

Status of the NOvA Experiment

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Robert Plunkett, for the NOvA Collaboration

Fermilab, P.O. Box 500, Batavia, IL 60510, USA

plunk@fnal.gov

Abstract. The NOvA experiment, using the existing NuMI beamline, is planned for construction at Ash River, Minnesota. The experiment will provide a measurement of, or strong limit on the neutrino mixing angle θ_{13} , and for sufficiently strong mixing, establish the hierarchy of the neutrino masses.

1. Introduction

The discovery of neutrino oscillations in atmospheric and terrestrial neutrino experiments [1], has focused the attention of the physics community on the unusual pattern of the mixing among the neutrino mass eigenstates. In particular, the mixing of the weak eigenstate ν_e with the mass eigenstate ν_3 has been limited to relatively small values [2], in sharp contrast with the other mixing angles, which are near-maximal. A number of planned experiments will measure or further constrain this angle. In addition, there are a number of fundamental parameters of the neutrino system which are not currently known – one of the most important of which is the ordering, or hierarchy, of the neutrino mass eigenstates ν_1 , ν_2 , and ν_3 (since the oscillation phenomenon in vacuum measures only mass differences). The NOvA experiment is proposed for construction at a site (Ash River) in northern Minnesota, with a baseline of 810 km with respect to the existing NuMI beam facility at Fermilab. Together with upgrades to the intensity of the NuMI beamline, NOvA will provide a powerful tool for addressing the most pressing questions in the area of neutrino physics.

2. Construction of Detector and Beamline

The NuMI beamline at Fermilab will be significantly upgraded as part of the NOvA project. Since production of neutrinos is proportional to beam power on the target, the flux into an experiment depends both on the beam intensity and on the frequency with which it is sent to a production target. The expected end of the Collider program at the Fermilab Tevatron will make the Recycler, currently used to cache antiprotons, available as a storage ring for protons. This allows the Fermilab Main Injector magnets to complete a full cycle of acceleration and extraction every 1.3s, an increase over the current 2.2 s. Together with modest increases in pulse intensity, this should provide 700 kW of beam power to NOvA. Further accelerator projects may increase the power to greater than 1 MW.

The detector location is 14.6 mradians off-axis, so the Main Injector proton beam will create a narrow-band neutrino beam with a spectrum sharply peaked around 2 GeV.

The NOvA detector design is fully active. It will be constructed of 15.6 m PVC extrusions filled with a mixture of mineral oil and liquid scintillator. Readout of each extrusion tube is via an imbedded wave-length shifting fiber to an HPD. There are 384 tubes per plane and a design with 18kT mass includes approximately 1200 layers.

The fine segmentation (approx. 4 cm transversely and 6 cm longitudinally) and transparency of the detector medium allows good (~30%) efficiency for identification of electron showers induced by ν_e CC events, with acceptable background rates. Figure 2 shows a Monte Carlo representation of an electron-induced shower in the NOvA detector.

Backgrounds to the appearance signal arise from mis-identified ν_μ NC and CC events and intrinsic ν_e 's in the NuMI beam. The narrow-band off-axis beam causes NC events to migrate to low energies not underneath the signal region. Similarly, intrinsic beam ν_e 's are spread out in energy, reducing the background level from this source to manageable levels. Mis-identified ν_μ CC events are rejected by pattern recognition using an ANN or other similar algorithm.

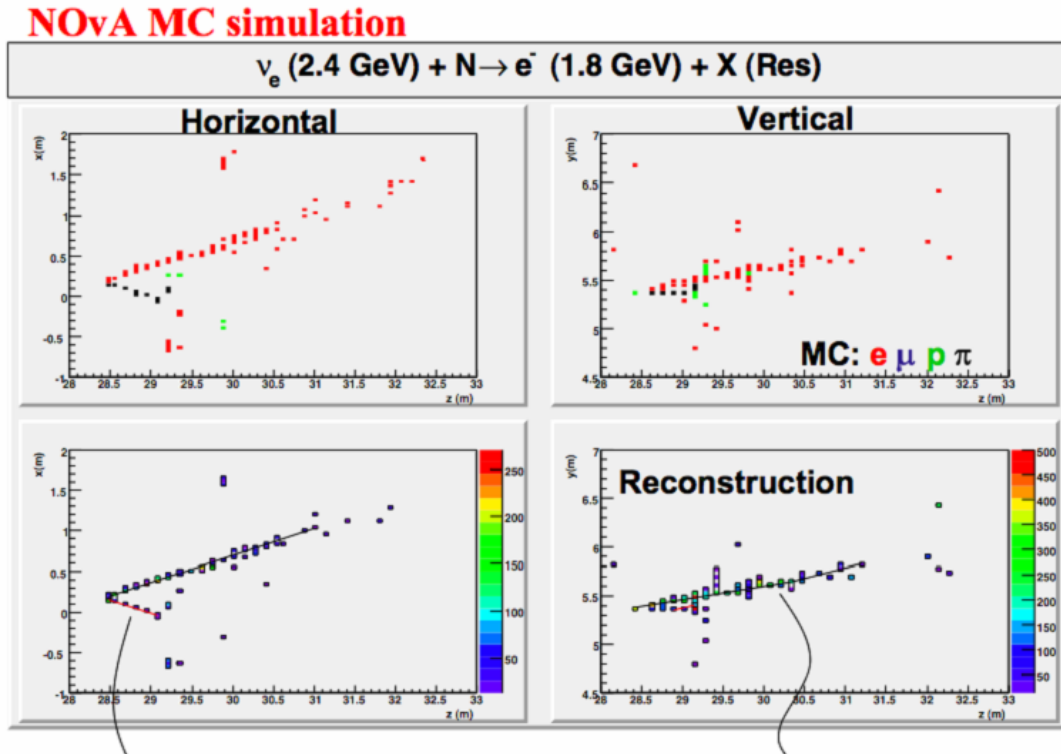


Figure 1: Monte Carlo display of raw and reconstructed data in a candidate event in NOvA.

3. Physics Sensitivities

The combination of active detector and intense neutrino beam discussed above gives NOvA sensitivity to a large range of values of $\sin^2 2\theta_{13}$ (appearing in the combination $\sin\theta_{23}\sin^2 2\theta_{13}$). At the NOvA baseline, matter effects on the ν_e component of the oscillating neutrino state cannot be neglected. These depend on the mass hierarchy, increasing the appearance probability for neutrinos for normal hierarchy over the inverted case (and conversely for anti-neutrinos). A further complication for all NOvA measurements is the effect of a possible CP-violating phase δ in the mixing matrix. Optimized running for NOvA with a mixture of both neutrino and anti-neutrino beams is therefore to be expected. Figure 2 shows the sensitivity for detection of non-zero θ_{13} for a typical NOvA running scenario, presented as a function of δ .

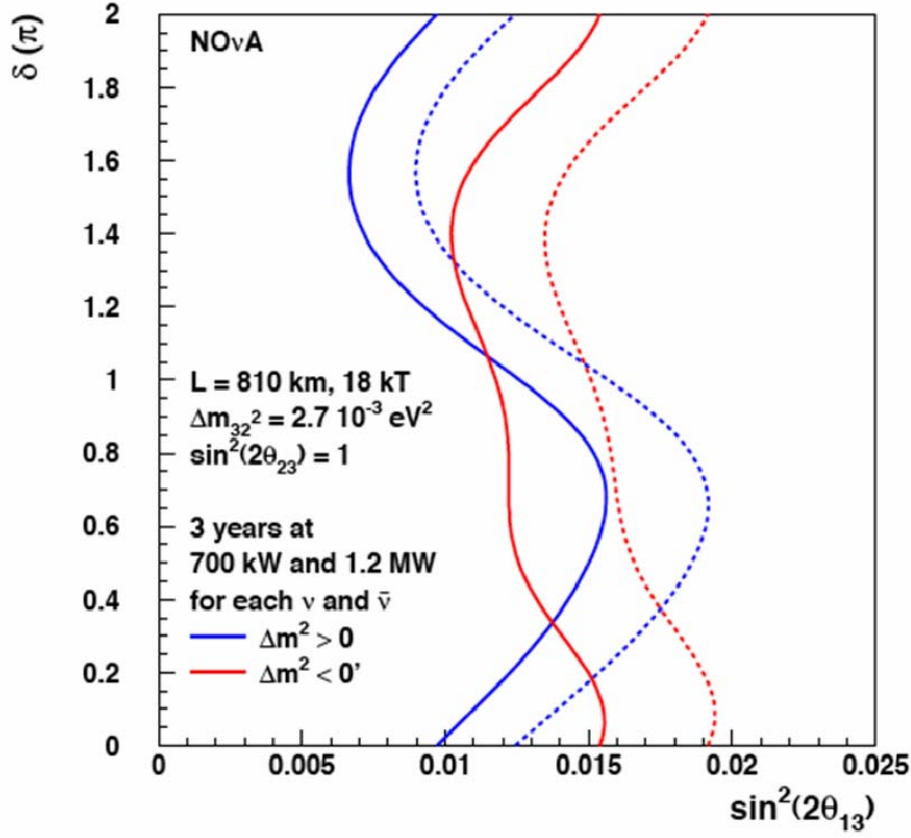


Figure 2: Three- σ sensitivity to establish non-zero θ_{13} for an 18 kT NOvA detector with two running scenarios. Dotted curves show results for NuMI beam running at 700 kW, and solid curves for 1.2 MW of beam power.

Matter effects due to the long NOvA baseline provide the mechanism by which the experiment will address the question of whether the neutrino mass eigenstate differences are grouped as $\Delta m(\text{solar}):\Delta m(\text{atmospheric})$ or in the inverted hierarchy $\Delta m(\text{atmospheric}):\Delta m(\text{solar})$ (in increasing order of mass). The matter effects are exploited by comparison of measurements using neutrino and anti-neutrino beams. These measurements are also affected by the possible CP phase δ . In Figure 3, one sees the 95% confidence limit curves for NOvA to distinguish the two situations by running with different beam powers. The contours are closed below the CHOOZ limit for approximately $\frac{1}{2}$ of the allowed CP phases in each of the two cases of hierarchy. It is important to notice that addition of expected information from the T2K experiment improves the experiment significantly for all values of δ . Here NOvA provides the vital information on neutrino-antineutrino differences, which can be combined with the appearance probabilities which will be measured by T2K at a different baseline.

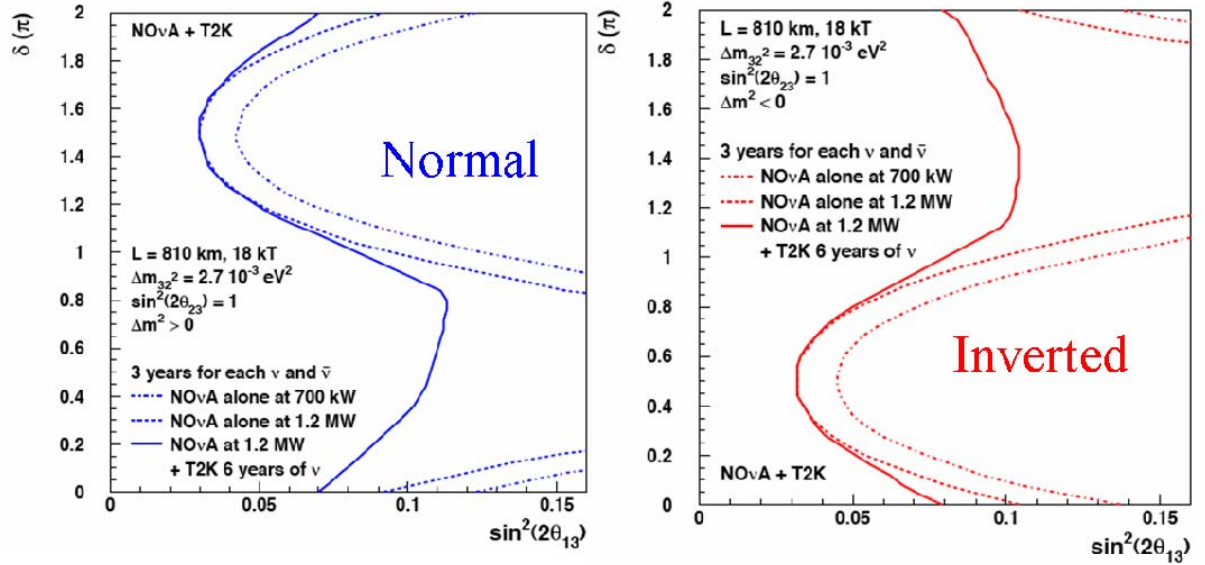


Figure 3: Sensitivity of NOvA and NOvA/T2K experiments to the neutrino mass hierarchy. Contours represent values of the parameters for which a 95% confidence level separation is possible.

4. Conclusions

The NOvA experiment represents the next step in the long-baseline neutrino program using the Fermilab NuMI facility. In addition to sensitivity to a wide range of θ_{13} and the ability to enable discrimination between the mass hierarchy scenarios, it will provide a precision measurement of the parameters of nm mixing, currently being addressed by MINOS. Together with data from reactor experiments, which measure θ_{13} directly, NOvA may allow the determination of the octant of the mixing angle θ_{23} . NOvA will also provide clues to future directions of neutrino physics. For example, the results of the comparison between neutrino and anti-neutrino measurements will likely indicate if extremely high-precision neutrino sources such as a neutrino factory will be needed to unravel the puzzle of CP- violation in the neutrino sector.

5. Acknowledgments

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